3. RADIONUCLIDE CONTAMINANTS IN THE ENVIRONMENT

Waste zone, vadose zone, and aquifer samples are collected routinely around the RWMC and are analyzed for a variety of radionuclides. Results from monitoring of radionuclides for FY 2003 are presented in this section. Historical data collected since FY 1997 also are summarized for perspective and to identify trends or lack thereof.

Radionuclide concentrations greater than 3σ and greater than the sample-specific minimum detectable activity (MDA) are referred to throughout this section as positive detections. Concentrations that are greater than 2σ and less than or equal to 3σ are referred to as statistically positive detections.

When the laboratory analysis results in a statistically positive detection of one or more actinides (i.e., Am-241, Np-237, Pu-238, and Pu-239/240) in aquifer samples, the laboratory pulls another aliquot from the sample container and conducts another analysis of the sample to confirm the detection. When the second analysis fails to confirm the presence of the actinide, the result is referred to throughout this section as an unconfirmed detection. In FY 2003, protocol for lysimeter samples was changed so that confirmation analyses are no longer conducted for actinide detections. The revised actinide protocol for lysimeters favors acquisition of data for various other priority analytes over confirmation of sporadic actinide detections.

3.1 Americium-241

Approximately 1.83E+05 Ci of Am-241 was disposed of in the SDA, and approximately 3.25E+04 Ci of Am-241 is expected to be generated over time through Pu-241 radioactive decay. The primary source of Am-241 and Np-237 in the SDA is the Rocky Flats Plant (RFP)[a] Series 741 sludge (i.e., first-stage wastewater sludge). An area in the central part of Pit 10 was identified as the Americium/Neptunium Focus Area for the OU 7-13/14 Probing Project.

3.1.1 Waste Zone

Approximately 10 mL of soil moisture was collected from Waste-Zone Lysimeter 741-08-L1 on September 8, 2003, but the volume was not sufficient to analyze for Am-241. However, the sample was analyzed for 13 targeted gamma-emitting radionuclides (Mn-54, Co-60, Zn-65, Ru-106, Ag-108m, Ag-110m, Sb-125, Cs-134, Cs-137, Ce-144, Eu-152, Eu-154, and Eu-155); plus any other positively detected anthropogenic, or unusually high, naturally occurring gamma emitters. No gamma-emitting radionuclides were detected.

3.1.2 Vadose Zone

3.1.2.1 Lysimeter Samples at Depths of 0 to 35 ft. Fourteen Am-241 analyses were performed on soil-moisture samples collected from 11 shallow lysimeters in and around the SDA in FY 2003, with no positive detections. Results for Am-241 in the shallow vadose zone samples, since routine monitoring began in 1997, are summarized in Figure 3-1. Sporadic detections occur, but no apparent trends for Am-241 are exhibited in the shallow lysimeters.

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a. The Rocky Flats Plant is located 26 km (16 mi) northwest of Denver, Colorado. In the mid-1990s, it was renamed the Rocky Flats Environmental Technology Site. In the late 1990s, it was again renamed, to its present name, the Rocky Flats Plant Closure Project.

		Americium-241 RWMC Lysimeters (0–35 ft)															
FY	Qtr	98-1 L35	98-4 L38	98-5 L39	D15-DL07	PA01-L15	PA02-L16	PA03-L33	W05-L25	W06-L27	W08-L13	W08-L14	W09-L23	W23-L07	W23-L08	W23-L09	W25-L28
1997	1																
	2																
	3																
	4																
1998	1																
	2							4.2									
	3					8.8											
	4																
1999	1			0.8												0.8	
	2																
	3																
	4																
2000	1																
	2			0.3													
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
Key		Analysis was performed, but americium-241 was not detected.															
		Americium-241 was detected (pCi/L).															
		If more than one positive detection occurred in a single quarter, then only the highest concentration is listed. Note: RBC = 4.76 pCi/L FY = fiscal year RBC = 1E-05 risk-based concentration RWMC = Radioactive Waste Management Complex															

Figure 3-1. Occurrences of americium-241 detections in the shallow lysimeters since Fiscal Year 1997.

3.1.2.2 Lysimeter Samples at Depths of 35 to 140 ft. Twenty-eight Am-241 analyses were performed on soil-moisture samples collected from 12 intermediate-depth lysimeters in and around the SDA in FY 2003, with no positive detections. Results for the intermediate vadose zone samples, since

routine monitoring began in 1997, are summarized in Figure 3-2. There are sporadic detections, but no apparent trends for Am-241 in the intermediate-depth lysimeters.

		Americium-241 RWMC Lysimeters (35–140 ft)													
FY	Qtr	D06-DL01	D06-DL02	D15-DL06	I1S-DL09	I2S-D	I3S-DL13	I4S-DL15	I5S-DL16	O2S-DL20	O3S-DL22	O4S-DL24	O5S-DL25	O7S-DL28	TW1-DL04
1997	1														
	2														
	3														
	4														
1998	1														
	2														
	3			2.4											
	4														
1999	1	0.8													
	2														
	3														
	4														
2000	1														
	2														1.9
	3														
	4														
2001	1														
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														
2003	1														
	2														
	3														
	4														
Key		Analysis was performed, but americium-241 was not detected.													
		Americium-241 was detected (pCi/L).													
		If more than one positive detection occurred in a single quarter, then only the highest concentration is listed. Note: RBC = 4.76 pCi/L FY = fiscal year RBC = 1E-05 risk-based concentration RWMC = Radioactive Waste Management Complex													

Figure 3-2. Occurrences of americium-241 detections in intermediate-depth (35- to 140-ft) lysimeters since Fiscal Year 1997.

3.1.2.3 Lysimeter Samples at Depths Greater than 140 ft. Seventeen Am-241 analyses were performed on perched water and deep-suction lysimeter samples collected from two perched wells and six lysimeters in and around the SDA in FY 2003, with no positive detections. Results for the samples,

since routine monitoring began in 1997, are summarized in Figure 3-3. The "I" and "O" wells were installed between November 1999 and March 2000, and the first samples were collected in June 2000. No detections of Am-241 have occurred in any perched water or vadose zone samples at this depth interval in the 6-year reporting period addressed in this report.

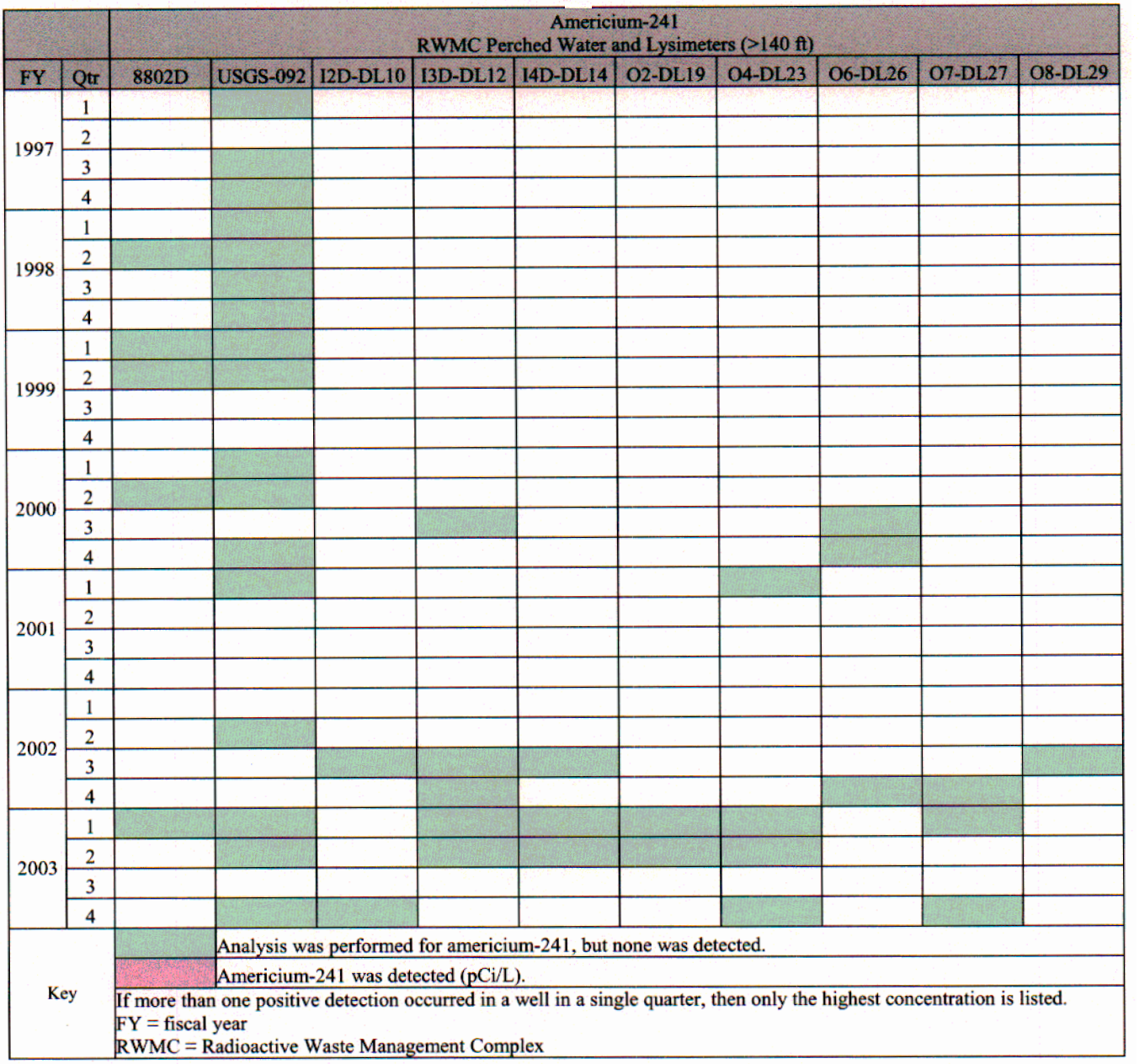

Figure 3-3. Occurrences of americium-241 detections in the deep-depth (>140 ft) lysimeters since Fiscal Year 1997.

3.1.3 Aquifer

Sixty-four Am-241 analyses were performed on aquifer samples collected from 15 monitoring wells in the vicinity of the RWMC in FY 2003, with no positive detections. Samples were collected in November 2002 and February, April, May, and August 2003. The results are summarized in Figure 3-4.

Results for the aquifer samples show sporadic detections but no evident trends. None of the positive detections exceeded the maximum contaminant level (MCL) of 15 pCi/L (total alpha) or the calculated aquifer 1E-05 RBC of 4.6 pCi/L.

		Americium-241 RWMC Aquifer-Monitoring Wells															
FY	Qtr	A11 A31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
1993	All																
1994	All																
1995	All																
1996	All																
1997	1–4																
1998	1										1.13						
	2																
	3										1.97						
	4																
1999	1																
	2																
	3			0.026													
	4																
2000	1																
	2																
	3																
	4											0.027					
2001	1																
	2																
	3																
	4							0.039					0.066				0.058
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																

Key

Analysis was performed, but americium-241 was not detected.

Americium-241 was detected (pCi/L).

If more than one positive detection occurred in a single quarter, then only the highest concentration is listed.
Note: RBC = 4.76 pCi/L. MCL = 15 pCi/L total alpha.
FY = fiscal year
MCL = maximum contaminant level
RBC = 1E-05 risk-based concentration
RWMC = Radioactive Waste Management Complex
USGS = United States Geological Survey

Figure 3-4. Occurrences of americium-241 detections in aquifer samples around the Radioactive Waste Management Complex since Fiscal Year 1997.

3.1.4 Summary of Americium-241

Americium-241 was not detected in any of the soil-moisture or aquifer samples collected in FY 2003. Historical detections in the vadose zone are depicted with the locations of waste disposals known to contain Am-241 (see Figure 3-5). All but one of the mapped detections are one-time events that have not been substantiated with subsequent detections in more than 3 years. Two detections were made in Lysimeter 98-5L39, located on the west end of the SDA near some mapped disposals, but no positive detections have been found in the four sampled quarters since the second quarter of FY 2000. Aquifer detections of Am-241 also are sporadic. Sporadic detections of Am-241 in the vadose zone and the aquifer since 1993 do not point to any evident spatial or temporal trends.

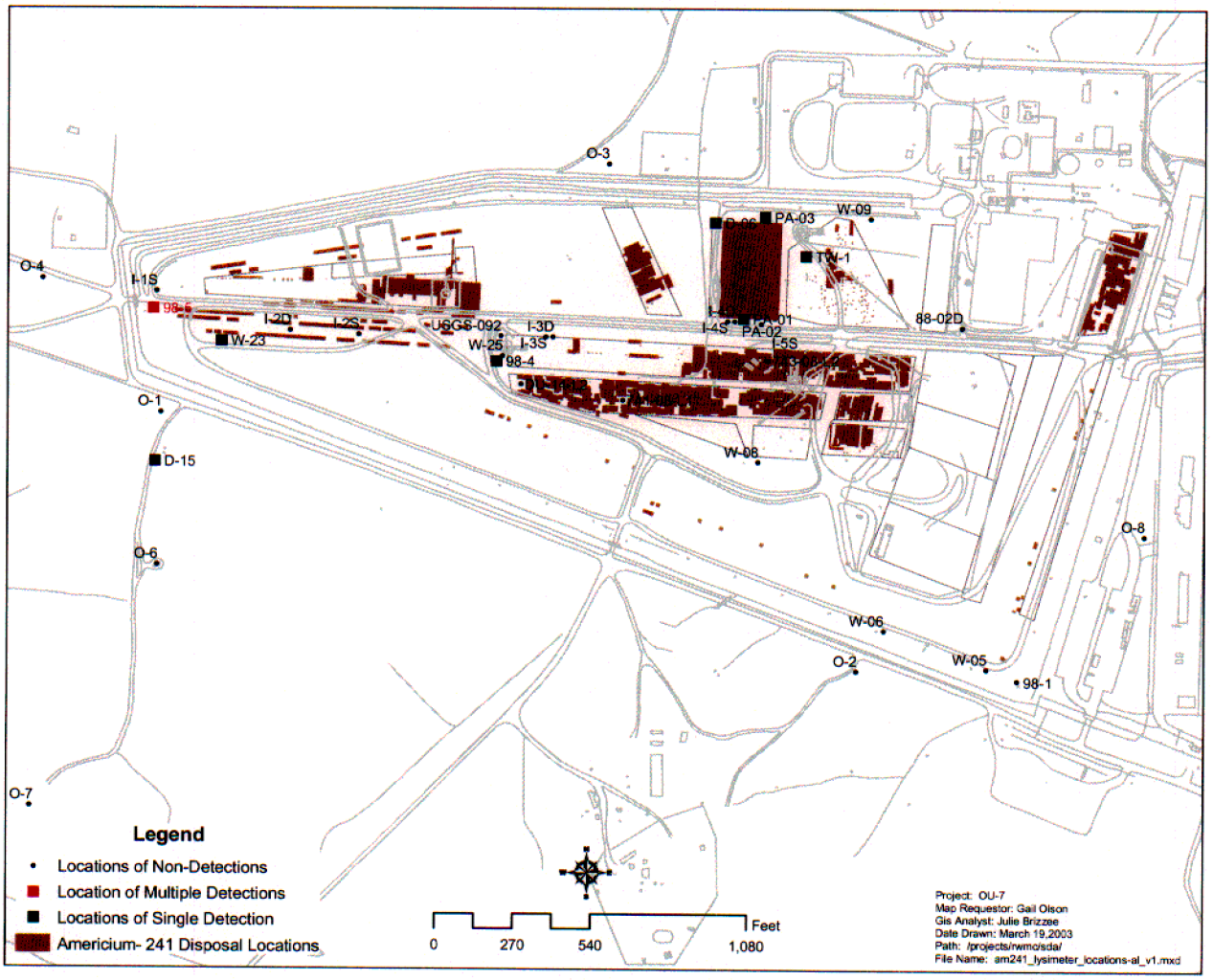

Figure 3-5. Americium-241 disposal locations and vadose zone detection locations at the Subsurface Disposal Area.

3.2 Carbon-14

Carbon-14 is an activation product generated by nuclear operations. Most of the C-14 inventory in the SDA is contained in activated steel. Some of the disposal inventory is in the form of reactor core components, including beryllium reflector blocks and end pieces from reactor cores. Most of the remaining activity is in ion-exchange resins. Typical C-14-bearing waste was disposed of in the SVRs or trenches in the earlier years of operation.

Soil Vault Rows 12 and 20 in the southeast corner of the SDA are known to contain large amounts of C-14 because of disposals of activated steel and beryllium blocks. Soil Vault Row 20 contains beryllium blocks from the Advanced Test Reactor, which contained approximately 12 Ci of C-14. Soil Vault Row 12 contains numerous disposals of what are believed to be activated stainless steel. Information gathered through conversations with past and present INEEL staff (Salomon 2003) indicates that these disposals are probably highly irradiated stainless-steel end pieces removed from Experimental Breeder Reactor II spent fuel elements. Spent fuel elements from Experimental Breeder Reactor II were sent to the Idaho Nuclear Technology and Engineering Center (INTEC) for processing after use. The stainless-steel end pieces were physically separated from the fuel in underwater basins at the Chemical Processing Plant (CPP) (now INTEC) facility, CPP-603, before uncontained disposal (in baskets, not sealed) at the RWMC. Ten shipments were sent from CPP-603 and placed in SVR 12. The rate of C-14 release from activated steel, presumably by corrosion, is being studied at SVR 12. Type B probes with vapor ports were installed in 2001, and initial sampling was conducted in 2002.[b]

3.2.1 Waste Zone

Approximately 10 mL of soil moisture was collected from Waste-Zone Lysimeter 741-08-L1 on September 8, 2003, but the volume was not sufficient to analyze for C-14; however, the sample was analyzed for gamma-emitting radionuclides with no positive detections.

Carbon-14 samples are collected quarterly from the functioning Type B vapor probes at SVRs 12 and 20. Sampling sites near SVRs 12 and 20 are shown in Figure 3-6. The C-14 samples are analyzed for C-14-specific activity (i.e., C-14 activity per unit mass of total carbon). Carbon-14 results for the functioning probes at SVR 12 are contained in Table 3-1. The results for C-14 analyses indicate that the C-14-specific activity in SVR 12 samples is two to three orders of magnitude above the typical background concentration of C-14, which is 6.5 pCi/g C. The concentration of H-3 in soil gas near SVR 12 also was measured and determined to be less than 600 pCi/L and probably considerably less than 100 pCi/L (i.e., near background levels). The absence of H-3 in the soil gas provides confidence that the C-14 originates from the activated stainless steel in SVR 12 rather than activated beryllium.[c]

Specific activity of C-14 in CO_2 has been measured in grab samples of soil gas collected from the Gas Sampling Port (GSP) -1 ports. Results for soil-gas samples are summarized in Table 3-2. These results are for samples collected using caustic solutions in bubblers before FY 2000 and in Tedlar bags after FY 2000. The SVR 20-IPV-5-VP3 soil-gas sampling port is located approximately 5 m (16 ft) from the beryllium waste, and the GSP-1 gas sampling ports are located approximately 0.8 to 1 m (2.6 to 3 ft) from the waste. The specific activity of C-14 in CO_2 is approximately a factor of 3 less at the more distant location, based on the samples from both ports on November 15, 2001, and August 23, 2002.

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b. B. G. Schnitzler Letter to M. M. Garland, August 21, 1995, "Radionuclide Inventories of Advanced Test Reactor Outer Shim Control Cylinder and Reflector Block Components," BGS-12-95, Idaho National Engineering and Environmental Laboratory.

c. The SVR 12 Type B vapor ports are approximately 210 ft from the nearest activated beryllium disposal location (personal communication with D. Mahnami, February 2004).

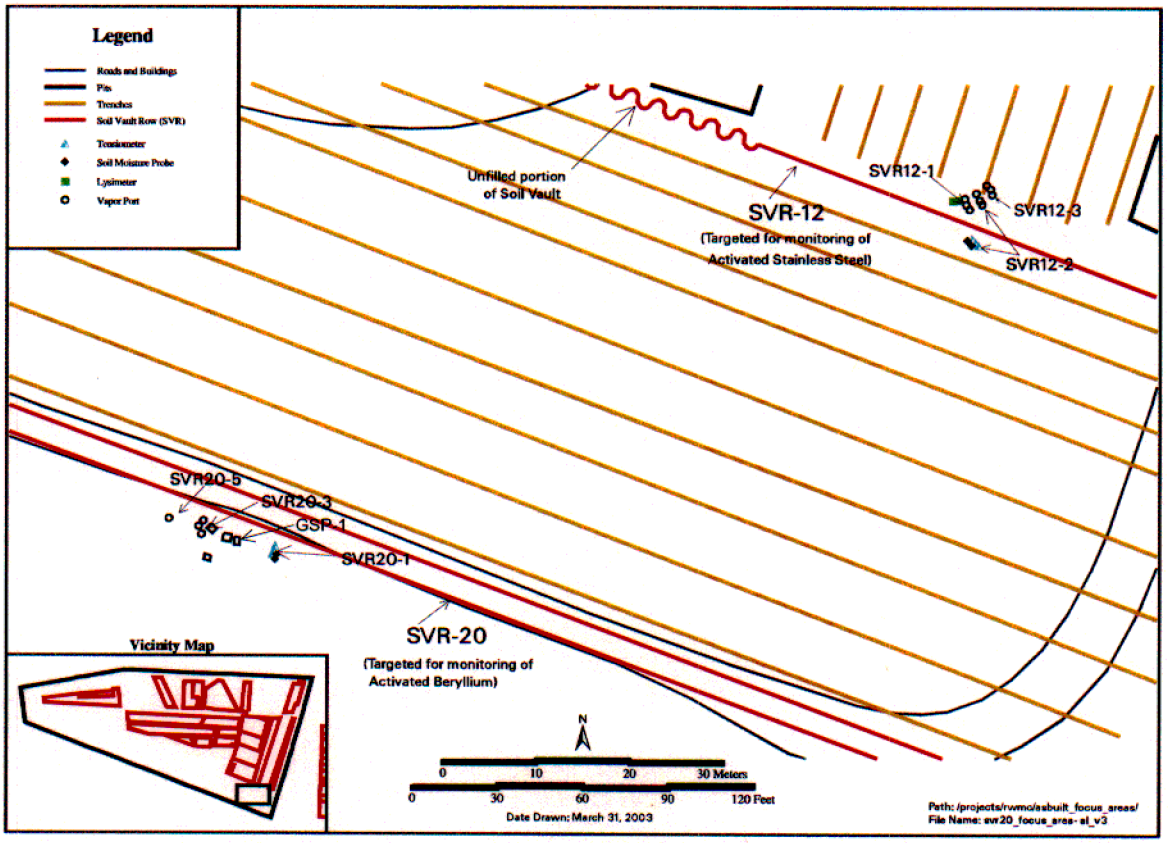

Figure 3-6. Vapor probes, tensiometers, lysimeters, and soil-moisture probes installed in the waste zone near or in Soil Vault Rows 12 and 20.

Table 3-1. Specific activity of carbon-14 (pCi [C-14]/g [C]) from vapor probes at Soil Vault Row 12.

Date	SVR-12-1-VP1	SVR-12-1-VP2	SVR-12-1-VP3	SVR-12-2-VP1	SVR-12-2-VP2	SVR-12-2-VP3	SVR-12-3-VP1	SVR-12-3-VP2	SVR-12-3-VP3
12/03/01	3,300	3,300	8,400	2,700	3,500	—[a]	2,900	3,000	8,200
2/20/02	2,100	450	—	1,400	—	—	2,000	1,500	16,000
5/23/02	990	990	2,800	1,400	840	630	1,200	1,600	370
8/13/02	1,200	1,200	1,600	1,300	1,000	380	2,200	1,200	480
8/23/02	—	—	—	—	—	—	—	—	—
11/13/02	710	560	<MDA[b]	1,500	590	<MDA	1,100	680	<MDA
2/3/03	880	680	<MDA	970	—	480	1,100	680	<MDA
5/15/03	710	480	230	820	550	280	480	680	110

a. Dash indicates that no sample was taken on that date.
b. Relative uncertainty >33%. The relative uncertainty of the other results is typically 5–10%. In addition, the CO_2 concentrations in these samples are relatively low.
c. In the analytical report, SVR-20-5-VP3 probe results apparently were switched with the SVR-12-1-VP3 results. The value reported here is considered the correct value for the sample.
MDA = minimum detectable activity
SVR = soil vault row

Table 3-2. Summary of carbon-14-specific activity (pCi [C-14]/g [C]) in CO_2 from soil-gas samples collected at Soil Vault Row 20.

	GSP-1	GSP-1	GSP-1	SVR 20-IPV-5-VP3
Depth (m)	2.7	4.5	6.2	5.4
Date				
6/5/96	1.7E+04	—	2.3E+04	—
7/2/96	—	3.4E+04	2.5E+04	—
12/12/96	1.3E+05	4.2E+04	3.3E+04	—
11/12/97	4.4E+04	2.0E+04	1.2E+04	—
11/15/01	3.6E+05	1.6E+05	2.4E+05	8.3E+04
2/20/02	—	—	—	2.8E+04
5/2/02	1.7E+05	1.4E+05	1.3E+05	—
5/23/02	—	—	—	3.1E+04
8/23/02	1.3E+05	1.3E+05	1.4E+05	3.7E+04
11/13/02	—	—	—	2.4E+04
11/5/03	—	—	—	4.1E+04[c]

GSP = gas sampling port
SVR = soil vault row

3.2.2 Vadose Zone

3.2.2.1 Lysimeter Samples at Depths of 0 to 35 ft. Fourteen C-14 analyses were performed on soil-moisture samples collected from nine shallow lysimeters in and around the SDA in FY 2003, with no positive detections. Results for C-14 in shallow vadose zone samples, since routine monitoring began in 1997, are summarized in Figure 3-7. Sporadic detections occur, but no apparent trends are exhibited in the shallow lysimeters.

		Carbon-14 RWMC Lysimeters (0–35 ft)															
FY	Qtr	98-1L35	98-4L38	98-5L39	D15-DL07	PA01-L15	PA02-L16	PA03-L33	W05-L25	W06-L27	W08-L13	W08-L14	W09-L23	W23-L07	W23-L08	W23-L09	W25-L28
1997	1																
	2																
	3						16			11							
	4						19										
1998	1																
	2																
	3						22										
	4																
1999	1																
	2																
	3		24				26										
	4																
2000	1																
	2																
	3																
	4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																
Key		Analysis was performed, but carbon-14 was not detected.															
		Carbon-14 was detected (pCi/L).															
		If more than one positive detection occurred in a single quarter, then only the highest concentration is listed. Note: RBC = 307 pCi/L FY = fiscal year RBC = 1E-05 risk-based concentration RWMC = Radioactive Waste Management Complex															

3.2.2.2 Lysimeter Samples at Depths of 35 to 140 ft. Fifteen C-14 analyses were performed on soil-moisture samples collected from 12 lysimeters in and around the SDA in FY 2003, with one positive detection (see Table 3-3). Results for C-14 in intermediate-depth vadose zone samples, since routine monitoring began in 1997, are summarized in Figure 3-8. The positive result did not exceed the primary drinking water MCL of 2,000 pCi/L or the calculated aquifer 1E-05 RBC of 307 pCi/L. The MCL and aquifer RBC are not applicable to soil-moisture samples, but are used as a basis for comparison.

Table 3-3. Carbon-14 detection in Fiscal Year 2003 Subsurface Disposal Area vadose zone soil-moisture samples from the 35- to 140-ft depth interval.

Lysimeter	Depth (ft)	Sample Date	Sample Result ± 1σ (pCi/L)	MDA (pCi/L)	Local Soil-Moisture Background[a] (pCi/L)	Aquifer RBC[b] (pCi/L)
I2S-DL11	92	07/21/03	**46 ± 14**[c]	46	Nondetect	307

a. The local soil-moisture background concentration for carbon-14 is defined as a nondetect (i.e., a result less than or equal to its MDA and less than or equal to three times its reported 1σ uncertainty).
b. RBC = 1E-05 for drinking water. The RBCs for the aquifer are provided here as a basis of comparison.
c. Black bold font indicates sample concentrations less than the RBC, but exceeding local soil-moisture background concentrations (see footnote a).
MDA = minimum detectable activity
RBC = risk-based concentration
SDA = Subsurface Disposal Area

		Carbon-14 Lysimeters (35–140 ft)													
FY	Qtr	D06 DL01	D06-DL02	D15-DL06	I1S-DL09	I2S-DL11	I3S-DL13	I4S-DL15	I5S-DL16	O2-DL20	O3-DL22	O4-DL24	O5-DL25	O7-DL28	TW1-DL04
1997	1														
	2														
	3														
	4														
1998	1														
	2														
	3														
	4														
1999	1														
	2														
	3														
	4														
2000	1														
	2														
	3														
	4														
2001	1														
	2														
	3														
	4														
2002	1														
	2														
	3														
	4														
2003	1														
	2														
	3														
	4					46									
Key		Analysis was performed for carbon-14, but none was detected.													
		Carbon-14 was detected (pCi/L).													
		If more than one positive detection occurred in a well in a single quarter, then only the highest concentration is listed. FY = fiscal year													

Figure 3-8. Occurrences of carbon-14 detections in intermediate-depth (35 to 140 ft) lysimeters since Fiscal Year 1997.

3.2.2.3 *Lysimeter and Perched Water Samples at Depths Greater than 140 ft.*

Seven C-14 analyses were performed on perched water and deep-suction lysimeter samples collected from one perched well and five lysimeters in and around the SDA in FY 2003, with no positive detections. Results for C-14 in deep vadose zone samples, since routine monitoring began in 1997, are summarized in Figure 3-9.

		Carbon-14 RWMC Perched Water and Lysimeters (>140 ft)									
FY	Qtr	8802D	USGS-092	I2D-DL10	I3D-DL12	I4D-DL14	O2-DL19	O4-DL23	O6-DL26	O7-DL27	O8-DL29
1997	1										
	2										
	3		12								
	4		13								
1998	1										
	2	20	20								
	3										
	4										
1999	1										
	2										
	3										
	4										
2000	1										
	2										
	3										
	4										
2001	1										
	2										
	3										
	4										
2002	1										
	2		134								
	3										
	4										
2003	1										
	2										
	3										
	4										

Key	
	Analysis was performed for carbon-14, but none was detected.
	Carbon-14 was detected (pCi/L).
	If more than one positive detection occurred in a well in a single quarter, then only the highest concentration is listed. FY = fiscal year RWMC = Radioactive Waste Management Complex

Figure 3-9. Occurrences of carbon-14 detections in deep-depth (>140 ft) lysimeters since Fiscal Year 1997.

3.2.3 Aquifer

Sixty-three C-14 analyses were performed on aquifer samples collected from 15 monitoring wells in the vicinity of the RWMC in FY 2003, with one detection. The detection, however, did not meet all the criteria of a positive detection, since its result (0.7±0.2 pCi/L) was less than the MDA (0.8 pCi/L). Therefore, the project assigned a "J" data qualifier flag to the result to indicate it was not a valid detection. Carbon-14 occurrences in aquifer samples, since 1997, are summarized in Figure 3-10. Results for the RWMC aquifer samples show sporadic detections but no evident trends. None of the positive detections exceeded the MCL of 2,000 pCi/L or the calculated aquifer 1E-05 RBC of 307 pCi/L.

		Carbon-14 RWMC Aquifer-Monitoring Wells															
FY	Qtr	AllA31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
1997	1																
	2																
	3																
	4																
1998	1																
	2																
	3																
	4				3.0	6.7											
1999	1																
	2				4.4						4.9						
	3																
	4						11										
2000	1													5.3	1.8		
	2																
	3																
	4				2.1	3.2	4.0				2.8	3.3			2.2		
2001	1																
	2																
	3			2.8	2.9	3.3											4.5
	4									42							
2002	1																
	2							4.5		7.5							
	3	3.1															
	4	7.1											3.5				
2003	1																
	2																
	3																
	4																

Analysis was performed, but carbon-14 was not detected.

Carbon-14 was detected (pCi/L).

If more than one positive detection occurred in a single quarter, then only the highest concentration is listed.
Note: RBC = 307 pCi/L MCL = 2,000 pCi/L
FY = fiscal year
MCL = maximum contaminant level
RBC = 1E-05 risk-based concentration
RWMC = Radioactive Waste Management Complex
USGS = United States Geological Survey

Figure 3-10. Occurrences of carbon-14 detections in the aquifer-monitoring wells since Fiscal Year 1997.

3.2.4 Summary of Carbon-14

Carbon-14 in soil-gas samples collected near the beryllium block disposals in SVR 20 are approximately four orders of magnitude higher than background levels. Results for C-14 analyses in the waste zone at SVR 12 indicate that the C-14-specific activity in soil gas is approximately two orders of magnitude higher than the background level of 6.5 pCi of C-14 per gram of carbon. The concentration of C-14 in soil-gas samples near activated steel (SVR 12) is much lower than the concentration observed near activated beryllium (SVR 20). This difference is as expected because of the relatively low concentration of C-14 in stainless steel and the much slower corrosion rate of stainless steel.

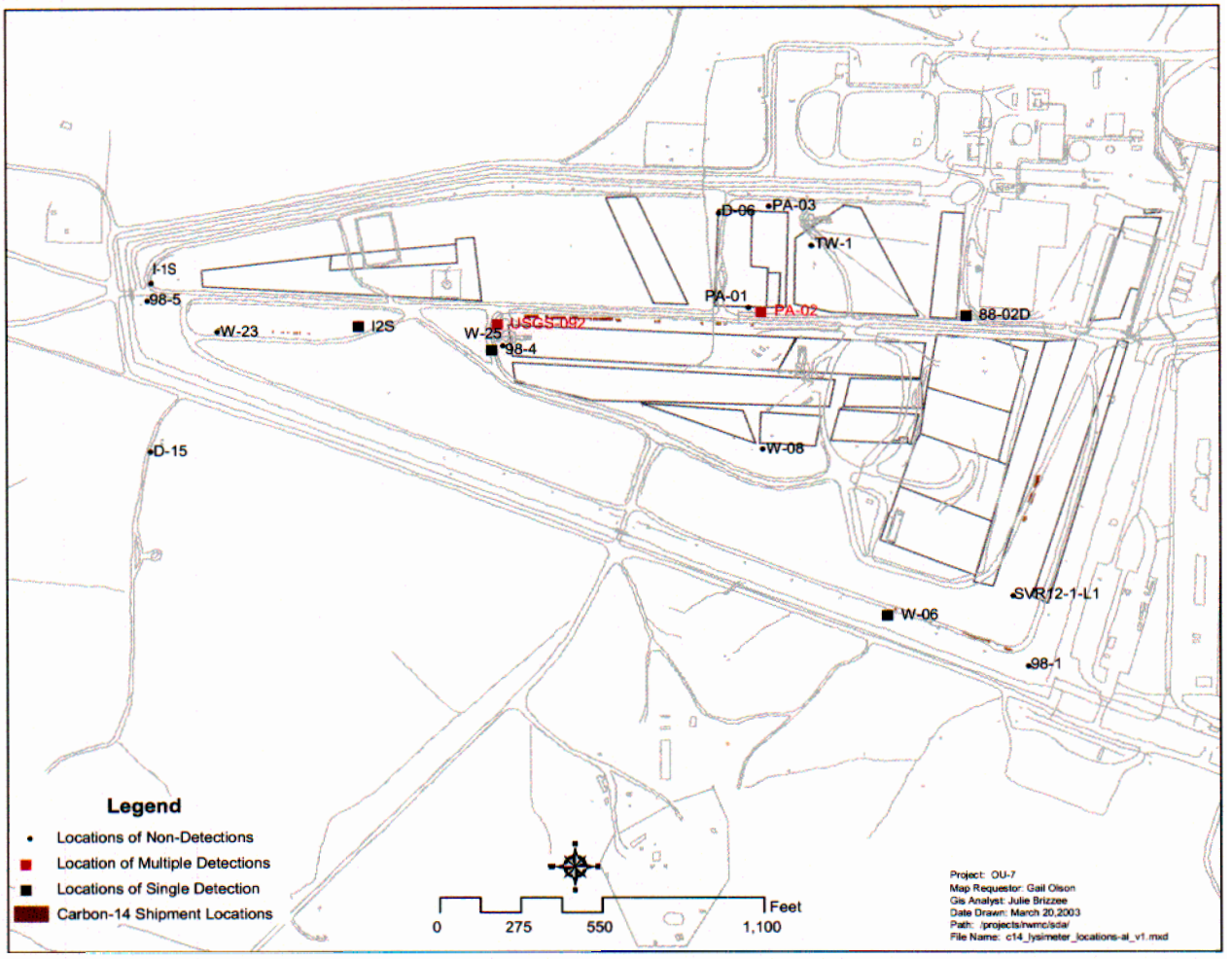

Figure 3-11. Carbon-14 disposal locations and vadose zone detection locations at the Subsurface Disposal Area.

Maximum concentrations of C-14 in vadose zone soil moisture and perched water since FY 1997 are shown in Table 3-4, and locations of detected C-14 in vadose zone samples are depicted in Figure 3-11 along with the known C-14 disposals. Carbon-14 was not detected in perched water or soil-moisture samples collected from the vadose zone in FY 2003, with the exception of I2S-DL11. The most frequent C-14 detections occurred in samples from the PA02-L16 shallow lysimeter (see Figure 3-7) and from the USGS-92 perched water well (see Figure 3-9). Most detections occurred between 1997 and 1999, with one in January 2002. Repeated positive detections in USGS-92 suggest that C-14 has migrated to the 67-m (220-ft) perched water region beneath the RWMC (see Holdren et al. 2002, Section 4). The concentration associated with the January 2002 sample from USGS-92 (i.e., 134 ± 38 pCi/L) is approximately 10 times higher than previous detections.

Table 3-4. Summary of maximum concentrations of carbon-14 in vadose zone soil-moisture and perched water samples at the Radioactive Waste Management Complex from Fiscal Year 1997 through 2003.[a]

Sampling Range (feet below land surface)	Fiscal Year [b]	Maximum Concentration ± 1σ (pCi/L)[c]	Sample Location
Lysimeters 0 to 35 ft	1997	19 ± 4	PA02-L16
	1998	21.8 ± 1.9	PA02-L16
	1999	26 ± 5	PA02-L16
	2000	ND	Various[d]
	2001	NA	—
	2002	NA	—
	2003	ND	Various
Lysimeters 35 to 140 ft	1997	NA	—
	1998	ND	Various
	1999	NA	—
	2000	NA	—
	2001	NA	—
	2002	NA	—
	2003	46 ± 14	I2S-DL11
Lysimeters >140 ft	1997	NA	—
	1998	NA	—
	1999	NA	—
	2000	NA	—
	2001	NA	—
	2002	NA	—
	2003	ND	Various
Perched water wells >140 ft	1997	13 ± 2	USGS-92
	1998	20 ± 4	USGS-92 and 8802D
	1999	ND	USGS-92
	2000	NA	—
	2001	NA	—
	2002	134 ± 38	USGS-92
	2003	ND	USGS-92

a. MCL = 2,000 pCi/L
b. Fiscal year spans from October 1 to September (e.g., Fiscal Year 1997 is October 1, 1996, to September 30, 1997).
c. NA = not analyzed ND = not detected
d. Various locations were sampled.
MCL = maximum contaminant level
USGS = United States Geological Survey

Trends are not apparent in any of the RWMC monitoring wells, and the detectable concentrations are well below the MCL of 2,000 pCi/L and the aquifer 1E-05 RBC of 307 pCi/L.

The lack of regularly occurring detections in the lysimeters or perched water wells in the vadose zone coupled with the possibility that an upgradient source of C-14 in the aquifer suggests that C-14 would not be a good calibration target for modeling concentrations in the aquifer. Maximum detections of C-14 in the aquifer since FY 1997 are presented in Table 3-5.

Table 3-5. Summary of maximum concentrations of carbon-14 in aquifer wells at the Radioactive Waste Management Complex from Fiscal Year 1997 through 2003.[a]

Fiscal Year[b]	Maximum Concentration ± 1σ (pCi/L)	Well Location
1997	ND[c]	Various[d]
1998	6.7 ± 0.9	M13S
1999	10.9 ± 0.7	M14S
2000	5.3 ± 0.5	M6S
2001	42.1 ± 1.4	M17S
2002	7.5 ± 0.9	M17S
2003	ND	Various[d]

a. MCL = 2,000 pCi/L
b. Fiscal year spans from October 1 to September 30 (e.g., Fiscal Year 1997 is October 1, 1996, to September 30, 1997).
c. ND = not detected
d. Various locations were sampled.
MCL = maximum contaminant level

3.3 Chlorine-36

Chlorine-36 is a radioisotope that is generated by nuclear reactor operations and weapons testing. In addition, it is produced in extremely low concentrations in the environment by cosmic-ray interactions with argon. It decays by the emission of beta particles, has a 30,100-year half-life, and was identified in the interim risk assessment as a contaminant of potential concern, primarily for the groundwater ingestion exposure pathways (Becker et al. 1998). Approximately 1.11 Ci of Cl-36 was disposed of in the SDA.

Results are presented for the vadose zone samples, but no analytical data for Cl-36 were collected from the waste zone or the aquifer samples in FY 2003. Lysimeters in the waste zone did not yield sufficient water for Cl-36 analyses in 2003, and the Cl-36 yearly sampling schedule for RWMC aquifer wells was not firmly established until the end of 2003.

3.3.1 Waste Zone

Approximately 10 mL of soil moisture was collected from Waste-Zone Lysimeter 741-08-L1 on September 8, 2003, but the volume was not sufficient to analyze for Cl-36; however, the sample was analyzed for gamma-emitting radionuclides with no positive detections.

3.3.2 Vadose Zone

3.3.2.1 Lysimeter Samples at Depths of 0 to 35 ft. Twenty-two Cl-36 analyses were performed on soil-moisture samples collected from 11 shallow lysimeters in and around the SDA in FY 2003, with three positive detections (see Table 3-6). The detections are associated with the

October 2002 sampling event, and the detected concentrations are considerably below the 1E-05 RBC of 144 pCi/L. Subsequent samples at these monitoring locations have not shown positive detections of Cl-36. The occurrence of Cl-36 detections in shallow lysimeters since 1997 is summarized in Figure 3-12; however, routine Cl-36 monitoring did not begin until October 2002. Sporadic detections occur, but no apparent trends are exhibited in the shallow lysimeters.

Table 3-6. Chlorine-36 detections in Fiscal Year 2003 Subsurface Disposal Area vadose zone soil-moisture samples from the 0- to 35-ft depth interval.

Lysimeter	Depth (ft)	Sample Date	Sample Result ± 1σ (pCi/L)	MDA (pCi/L)	Local Soil-Moisture Background[a] (pCi/L)	Aquifer RBC[b] (pCi/L)
W08-L13	11.3	10/21/02	**5.8 ± 1.4**[c]	4.8	Nondetect	144
W23-L07	18.8	10/21/02	**32.3 ± 1.6**[c,d]	3.3	Nondetect	144
98-5L39	10.5	10/21/02	**3.5 ± 0.9**[c]	3.0	Nondetect	144

a. The local soil-moisture background concentration for chlorine-36 is defined as a nondetect (i.e., a result less than or equal to its MDA and less than or equal to three times its reported 1σ uncertainty).
b. RBC = 1E-05 for drinking water. The RBCs for the aquifer are provided here as a basis of comparison.
c. **Black bold font** indicates sample concentrations less than the RBC, but exceeding local soil-moisture background concentrations (see footnote a).
d. The sample result for W23-L07 was assigned a "J" data qualifier flag, because the result of the laboratory duplicate (23.8 ● 1.5 pCi/L) did not meet precision criterion. Therefore, the reported concentration might not accurately represent the actual sample concentration and should therefore only be used as an estimated quantity. In other words, Cl-36 was definitely detected, but the reported concentration might not be accurate. Internal quality control test results, such as the laboratory duplicate (split) analysis, are not normally reported in these summary tables, but are included as a footnote to provide additional evidence of the presence of Cl-36 in this sample.
MDA = minimum detectable activity
RBC = risk-based concentration
SDA = Subsurface Disposal Area

		Chlorine-36 RWMC Lysimeters (0–35 ft)															
FY	Qtr	98-1L35	98-4L38	98-5L39	D15-DL07	PA01-L15	PA02-L16	PA03-L33	W05-L25	W06-L27	W08-L13	W08-L14	W09-L23	W23-L07	W23-L08	W23-L09	W25-L28
1997	1–4																
1998	1–4																
1999	1–4																
2000	1–4																
2001	1–4																
2002	1–4																
2003	1			3.5							5.8			32			
	2																
	3																
	4																
Key		Analysis was performed, but chlorine-36 was not detected.															
		Chlorine-36 was detected (pCi/L.)															
		If more than one positive detection occurred in a single quarter, then only the highest concentration is listed. Note: RBC = 144 pCi/L FY = fiscal year RBC = 1E-05 risk-based concentration RWMC = Radioactive Waste Managen t Complex															

Figure 3-12. Occurrence of chlorine-36 detections in shallow lysimeters.

3.3.2.2 Lysimeter Samples at Depths of 35 to 140 ft. Thirty-six Cl-36 analyses were performed on soil-moisture samples collected from 13 intermediate-depth lysimeters in and around the SDA in FY 2003, with three detections. One of the detections, however, did not meet the validation criteria for a positive detection, since its result (98 pCi/L) was less than the MDA (101 pCi/L). Therefore, the project assigned a "J" data qualifier flag to the I2S-DL11 result to indicate that it was not a valid detection. The other two detections are associated with the October 2002 sampling event, and the detected concentrations are considerably below the 1E-05 RBC of 144 pCi/L (see Table 3-7). Subsequent samples at these monitoring locations have not shown positive detections of Cl-36. The occurrence of Cl-36 detections in intermediate-depth lysimeters since 1997 is summarized in Figure 3-13; however, routine Cl-36 monitoring did not begin until October 2002. Sporadic detections occur, but no apparent trends are exhibited in the intermediate depth.

Table 3-7. Chlorine-36 detections in Fiscal Year 2003 Subsurface Disposal Area vadose zone soil-moisture samples from the 35- to 140-ft depth interval.

[redacted]Lysimeter	Depth (ft)	Sample Date	Sample Result ± 1σ (pCi/L)	MDA (pCi/L)	Local Soil-Moisture Background[a] (pCi/L)	Aquifer RBC[b] (pCi/L)
I1S-DL09	101	10/21/02	**5.6 ● 0.9**[c]	3.0	Nondetect	144
TW1-DL04	101.7	10/21/02	**3.7 ± 1.2**[c,d]	4.3	Nondetect	144

a. The local soil-moisture background concentration for chlorine-36 is defined as a nondetect (i.e., a result less than or equal to its MDA and less than or equal to three times its reported 1σ uncertainty).
b. RBC = 1E-05 for drinking water. The RBCs for the aquifer are provided here as a basis of comparison.
c. **Black bold font** indicates sample concentrations less than the RBC, but exceeding local soil-moisture background concentrations (see footnote a).
d. The sample result for TW1-DL04 was assigned a "J" data qualifier flag, because the concentration is below the MDA, but greater than three times its reported 1σ standard deviation. Even though the concentration is below the MDA, it is reported herein, because the result of the laboratory duplicate (10.6 ± 1.5 pCi/L) provides good evidence for the presence of Cl-36 in this sample. The reported concentration might not accurately represent the actual sample concentration and therefore should only be used as an estimated quantity. In other words, Cl-36 was definitely detected, but the reported concentration might not be precise. Laboratory internal quality control test results, such as duplicates (splits), are not normally reported in these summary tables, but are included as a footnote to provide additional evidence of the presence of Cl-36 in this sample.
MDA = minimum detectable activity
RBC = risk-based concentration
SDA = Subsurface Disposal Area

		Chlorine-36 Lysimeters (35–140 ft)													
FY	Qtr	D06-DL01	D06-DL02	D15-DL06	I1S-DL09	I2S-DL11	I3S-DL13	I4S-DL15	I5S-DL16	O2-DL20	O3-DL22	O4-DL24	O5-DL25	O7-DL28	TW1-DL04
1997	1–4														
1998	1–4														
1999	1–4														
2000	1–4														
2001	1–4														
2002	1–4														
2003	1				5.6										3.7
	2														
	3														
	4														
Key		Analysis was performed for chlorine-36, but none was detected.													
		Chlorine-36 was detected (pCi/L).													
		If more than one positive detection occurred in a well in a single quarter, then only the highest concentration is listed. FY = fiscal year													

Figure 3-13. Occurrences of chlorine-36 detections in intermediate-depth (35 to 140 ft) lysimeters.

3.3.2.3 Lysimeter and Perched Water Samples at Depths Greater than 140 ft. Sixteen Cl-36 analyses were performed on samples collected from four lysimeters and two perched water wells in and around the SDA in FY 2003, with one positive detection (see Table 3-8). The detection is associated with a sample collected from the USGS-92 perched water well in October 2002, with a concentration considerably below the 1E-05 RBC of 144 pCi/L. Subsequent perched water samples at this monitoring location have not shown positive detections of Cl-36. The occurrence of Cl-36 detections since 1997 are summarized in Figure 3-14; however, routine Cl-36 monitoring did not begin until October 2002. Sporadic detections occur, but no apparent trends are exhibited in the deeper depths.

Table 3-8. Chlorine-36 detection in Fiscal Year 2003 Subsurface Disposal Area vadose zone soil-moisture and perched water samples from depths greater than 140 ft.

Lysimeter	Depth (ft)	Sample Date	Sample Result ± 1σ (pCi/L)	MDA (pCi/L)	Local Soil-Moisture Background[a] (pCi/L)	Aquifer RBC[b] (pCi/L)
USGS-92	214	10/22/02	**8.7 ± 1.0**[c]	2.9	Nondetect	144

a. The local soil-moisture background concentration for chlorine-36 is defined as a nondetect (i.e., a result less than or equal to its MDA and less than or equal to three times its reported 1σ uncertainty).
b. RBC = 1E-05 for drinking water. The RBCs for the aquifer are provided here as a basis of comparison.
c. **Black bold font** indicates sample concentrations less than the RBC, but exceeding local soil-moisture background concentrations (see footnote a).
MDA = minimum detectable activity
RBC = risk-based concentration
SDA = Subsurface Disposal Area
USGS = United States Geological Survey

		Chlorine-36 RWMC Perched Water and Lysimeters (>140 ft)									
FY	Qtr	8802D	USGS-092	I2D-DL10	I3D-DL12	I4D-DL14	O2-DL19	O4-DL23	O6-DL26	O7-DL27	O8-DL29
1997	1–4										
1998	1–4										
1999	1–4										
2000	1–4										
2001	1–4										
2002	1–4										
2003	1		8.7								
	2										
	3										
	4										
Key			Analysis was performed for chlorine-36, but none was detected.								
			Chlorine-36 was detected (pCi/L).								
		If more than one positive detection occurred in a well in a single quarter, then only the highest concentration is listed.									
		FY = fiscal year									
		RWMC = Radioactive Waste Management Complex									

Figure 3-14. Occurrences of chlorine-36 detections in deep-depth (>140 ft) lysimeters.

3.3.3 Aquifer

No RWMC aquifer samples were analyzed for Cl-36 in FY 2003. Chlorine-36 was not regarded as a WAG 7 contaminant of potential concern until late 2001; thus, no sample data exist before that time. The analytical priority and sampling and analysis schedule for Cl-36 was officially established in 2003.

The established frequency was set at once per year. Figure 3-15 summarizes the occurrence of Cl-36 detections in the aquifer since 1997.

		Chlorine-36 RWMC Aquifer-Monitoring Wells															
FY	Qtr	AllA31	M10S	M11S	M12S	M13S	M14S	M15S	M16S	M17S	M1S	M3S	M4D	M6S	M7S	OW-2	USGS-127
1997	1–4																
1998	1–4																
1999	1–4																
2000	1–4																
2001	1																
	2																
	3																
	4																
2002	1																
	2																
	3																
	4																
2003	1																
	2																
	3																
	4																

Analysis was performed, but chlorine-36 was not detected.

Chlorine-36 was detected (pCi/L).

If more than one positive detection occurred in a single quarter, then only the highest concentration is listed.
Note: MCL = 700 pCi/L
FY = fiscal year
MCL = maximum contaminant level
RBC = 1E-05 risk-based concentration
RWMC = Radioactive Waste Management Complex
USGS = United States Geological Survey

Figure 3-15. Occurrences of chlorine-36 detections in the aquifer-monitoring wells since Fiscal Year 1994.

3.3.4 Summary of Chlorine-36

Analytical data to evaluate the nature and extent of Cl-36 contamination at the RWMC are limited, because Cl-36 did not become a target analyte for environmental monitoring until 2001. Chlorine-36 data also are limited, because past lysimeter and perched water sample volumes have been insufficient to analyze for Cl-36. Currently, there are not enough data for Cl-36 to draw any conclusions. In FY 2002, Cl-36 was added to the analytical priority list for lysimeter, perched water, and aquifer samples; in 2003, lysimeter sample volumes have increased because of improved sampling techniques. Chlorine-36 is fifth on the lysimeter analysis priority list with an established analysis frequency of four times per year. Once a year, analysis is performed for Cl-36 in the aquifer samples. If Cl-36 is detected in the aquifer samples, then the need to intensify the aquifer sampling frequency will be reviewed.

In FY 2003, seventy-four vadose zone sample analyses were performed, and seven positive detections were observed. Locations where Cl-36 was detected in the vadose zone are the same lysimeter and perched water wells where other contaminants have been detected in the past. Other detected contaminants are primarily uranium isotopes and Tc-99, although some wells also have a history of H-3 and C-14 detections. Detections are rare and appear to be confined to the vadose zone between 0 and 214 ft. All positive results were below the MCL of 700 pCi/L and the 1E-05 aquifer RBC of 144 pCi/L.

Maximum concentrations of Cl-36 in vadose zone soil moisture and perched water since October 2002 are shown in Table 3-9; Table 3-10 shows the aquifer maximums. Positive detections in USGS-92 suggest that Cl-36 has migrated to the 65-m (214-ft) perched water region beneath the RWMC (see Holdren et al. 2002, Section 4).

Table 3-9. Summary of maximum concentrations of chlorine-36 in vadose zone soil-moisture and perched water samples at the Radioactive Waste Management Complex from Fiscal Years 1997 through 2003.[a]

Sampling Range (feet below land surface)	Fiscal Year[b]	Maximum Concentration ± 1σ (pCi/L)[c]	Sample Location
Lysimeters 0 to 35 ft	1997	NA	—
	1998	NA	—
	1999	NA	—
	2000	NA	—
	2001	NA	—
	2002	NA	—
	2003	32.3 ± 1.6	W23-L07
Lysimeters 35 to 140 ft	1997	NA	—
	1998	NA	—
	1999	NA	—
	2000	NA	—
	2001	NA	—
	2002	NA	—
	2003	5.6 ± 0.9	I1S-DL09
Lysimeters >140 ft	1997	NA	—
	1998	NA	—
	1999	NA	—
	2000	NA	—
	2001	NA	—
	2002	NA	—
	2003	ND	Various
Perched water wells >140 ft	1997	NA	—
	1998	NA	—
	1999	NA	—
	2000	NA	—
	2001	NA	—
	2002	NA	—
	2003	8.7 ± 1.0	USGS-92

Table 3-9. (continued).

Sampling Range (feet below land surface)	Fiscal Year[b]	Maximum Concentration ± 1σ (pCi/L)[c]	Sample Location

a. MCL = 700 pCi/L
b. Fiscal year spans from October 1 to September (e.g., Fiscal Year 1997 is October 1, 1996, to September 30, 1997).
c. NA = not analyzed ND = not detected
d. Various locations were sampled.
MCL = maximum contaminant level
USGS = United States Geological Survey

Table 3-10. Summary of maximum concentrations of chlorine-36 in aquifer wells at the Radioactive Waste Management Complex from Fiscal Years 1997 through 2003.[a]

Fiscal Year[b]	Maximum Concentration ± 1σ (pCi/L)[c]	Well Location
1997	NA	—
1998	NA	—
1999	NA	—
2000	NA	—
2001	ND	Various[d]
2002	ND	Various
2003	NA	—

a. MCL = 700 pCi/L
b. Fiscal year spans from October 1 to September 30 (e.g., Fiscal Year 1997 is October 1, 1996, through September 30, 1997).
c. NA = not analyzed ND = not detected
d. Various locations were sampled.
MCL = maximum contaminant level

3.4 Tritium

Even though tritium is not a contaminant of potential concern, it is monitored because its distribution and migration are important to the overall understanding of contaminant movement in the vadose zone and aquifer, given there are uncertainties regarding whether the source of tritium is from the SDA or upgradient facilities. Tritium is produced naturally by interactions of cosmic rays and atmospheric gases, and tritium is produced by nuclear reactor operations. Beryllium in reactors undergoes (n,2n) and (n,α) reactions, generating substantial amounts of He-4, He-3, and H-3. The accumulation of helium and hydrogen atoms causes the beryllium to swell, requiring it to be replaced periodically. Between 1970 and 1993, irradiated reactor beryllium reflector waste from the Advanced Test Reactor, Engineering Test Reactor, and the Materials Test Reactor was buried in the SDA. These activated beryllium disposals contain a substantial fraction of the RWMC's total C-14 inventory and practically the entire RWMC H-3 inventory. The most recent disposal of beryllium consisted of six Advanced Test Reactor reflector blocks that were buried in SVR 20, approximately 96 m (315 ft) from the east row marker. These six blocks contain approximately 114,800 Ci of H-3 (predominantly as $^3H_2$, corrected for decay to September 2001) and about 12 Ci of C-14 (Mullen et al. 2003). Tritium and C-14 are released from the beryllium by corrosion.

3.4.1 Waste Zone

3.4.1.1 Ambient Air Sampling. Because a substantial amount of H-3 released from waste migrates to the atmosphere, ambient air sampling is included as part of the characterization of the waste zone and

source environment. The INEEL Environmental Monitoring Program conducted continuous sampling for airborne H-3 at SVR 20 from 1995 to 2002 (see Figure 3-16), using a sampling inlet set approximately 1 m (3 ft) above grade, approximately 1 m outside the edge of the backfilled auger hole. This sampling inlet was located downwind with respect to the nighttime primary wind direction at the RWMC. Moisture from the air samples was collected by pumping air at a constant rate through desiccant, which was collected when the desiccant was approximately 80% saturated. Atmospheric humidity conditions varied through the year, so there was no definite collection period.[d]

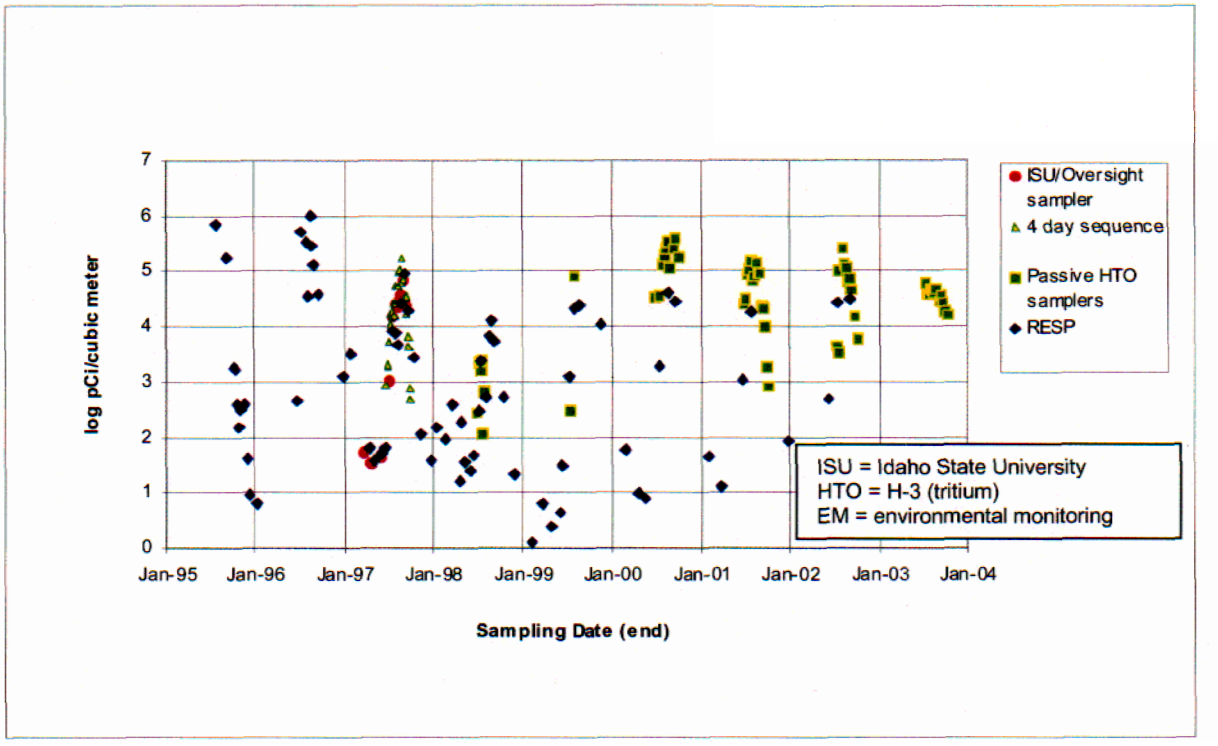

Figure 3-16. Airborne tritium concentration above the beryllium blocks at Subsurface Disposal Area Soil Vault Row 20.

Measurements by the Environmental Monitoring Program during 1994 and 1995 showed that H-3 concentration in air above SVR 20 ranges over several orders of magnitude during the year, with peak concentrations occurring in late summer. To develop more detailed release information, additional sampling is conducted during summer and fall. Passive airborne H-3 samplers (Wood and Workman 1992; Wood 1996) are used to sample over 1-week periods during the peak emission period. The passive samples are collected at three heights at a location that is approximately on the edge of the backfilled auger hole, downwind with respect to the primary daytime primary wind direction. Results from the INEEL Environmental Monitoring Program's samplers and the passive samplers show similar temporal fluctuations, but are not directly comparable. Based on results for FY 2000 through 2002, the passive samplers are exposed to air concentrations that are typically an order of magnitude greater than the environmental monitoring sampler. Estimated annual emissions of H-3 from buried activated beryllium at SVR 20 for Calendar Year (CY) 1995 through 2003 are shown in Table 3-11. Results for CY 1995 through 1999 are based on environmental monitoring sampling and results for CY 2000 through 2003 are

d. The collection periods for the environmental monitoring of airborne H-3 samples have ranged from a few weeks to 3 months, depending on humidity.

based on the passive sampling results. These data are used to develop emission estimates by calendar year for all disposed beryllium as required by 40 *Code of Federal Regulations* (CFR) 61, Subpart H, "National Emission Standards for Emissions of Radionuclides Other than Radon from Department of Energy Facilities."

Table 3-11. Estimated annual emission of tritium to air from buried activated beryllium at Soil Vault Row 20.

Year	1995	1996	1997	1998	1999	2000	2001	2002	2003
Emission (Ci)	30	30	3	0.5	3	20	10	10	5

3.4.1.2 Soil Gas. Since CY 1996,[e] soil-gas samples have been collected from the GSP-1 vapor ports, located approximately 60 to 100 cm (24 to 39 in.) from the beryllium at depths of 2.7, 4.5, and 6.2 m (8.9, 14.8, and 20.3 ft). The samples directly represent the concentrations during relatively brief sample collection periods in small (i.e., approximately 10 L) volumes of soil near the ports.

During FY 2003, the concentration of H-3 in soil moisture reached 8.0, 0.98, and 0.71 μCi/mL in soil 8.9, 14.8, and 20.3 ft deep, respectively (see Figures 3-17, 3-18, and 3-19). The concentration of H-3 in soil moisture appears to fluctuate with a period of 1 year. Fluctuations at each depth are correlated (Holdren et al. 2002), suggesting that concentrations at various depths are influenced similarly by soil and source conditions. From FY 1996 through FY 2003, H-3 concentrations in soil increased at a progressively greater rate. The average FY 2003 concentrations in soil 8.9, 14.8, and 20.3 ft deep are factors of 10, 40, and 20 times the pre-1997 concentrations.

3.4.2 Vadose Zone

Tritium has been detected in some of the routine vadose zone soil-moisture and perched water samples, with the highest concentrations found in samples from W06-L27 at about 3.7 m (12 ft) deep. Since tritium was not a WAG 7 contaminant of potential concern, the analysis priority for tritium in soil moisture was at the end of the priority list; thus, many data gaps exist. In 2003, tritium analysis was reprioritized (see Table 2-1), and a sampling and analysis frequency of three times per year was chosen.

e. The first samples were taken in FY 1995. No data were recovered for the 2.7-m (8.9-ft) deep sampling port because of sampling problems.

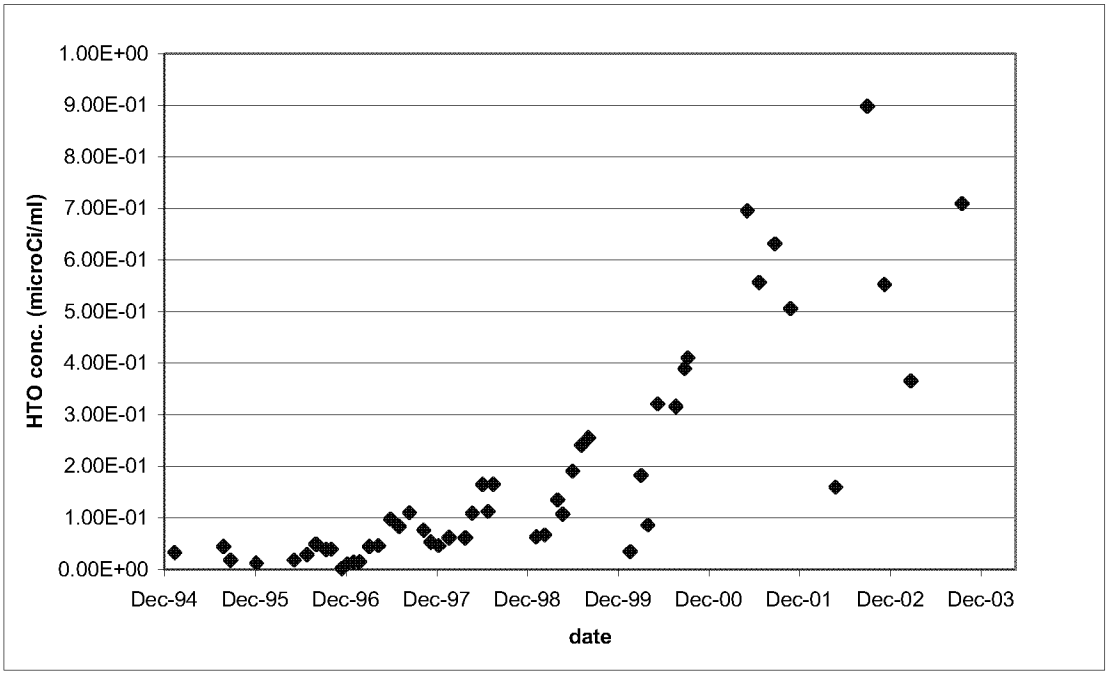

Figure 3-17. Tritium concentration in water vapor from the 8.9-ft-deep GSP-1 soil-gas sampling port.

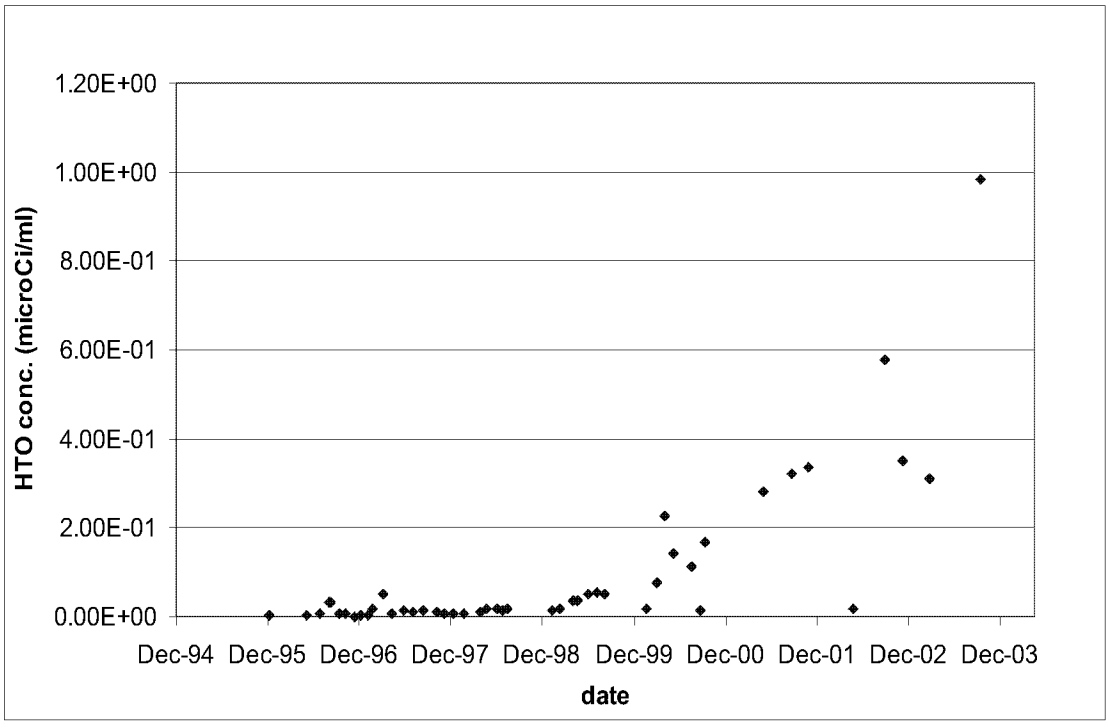

Figure 3-18. Tritium concentration in water vapor from the 15-ft-deep GSP-1 soil-gas sampling port.